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Electrostatic Discharge Inception on a High-Voltage Solar Array

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ELECTROSTATIC DISCHARGE INCEPTION ON A HIGH-VOLTAGE SOLAR ARRAY

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ABSTRACT

In this paper, results are presented of an experimental and theoretical study of arc inception on high-voltage solar array samples and a copper-quartz junction immersed in an argon plasma. The effects of arcing are investigated over a wide range of neutral gas pressures, ion currents, and electron number densities. It is shown that the arc rate increases with increasing ion collection current. This result can be considered as an additional argument in favor of the theoretical model of arc inception as due to secondary electron emission. The effect of surface conditioning (decrease of arc rate with time due to outgassing) is clearly demonstrated. Moreover, a considerable increase in arc rate due to absorption of molecules from atmospheric air has been confirmed. Arc sites were determined by employing a video-camera, and it is shown that the most probable sites for arc inception are triple-junctions, even though some arcs have been initiated in gaps between cells. Optical spectra of arcs were measured by employing a low-noise CCD camera. The analysis of spectra (240 to 800 nm) reveals intense narrow atomic lines (Ag, Cu, and H_α) and wide molecular bands that confirm a complicated mechanism of arc plasma generation. The results obtained seem to be important for understanding the arc inception mechanism. Finally, the arc threshold was increased to 500 V (from 120 V) by keeping the sample in vacuum (2 μTorr) for seven days.

1. INTRODUCTION

The current paper is a continuation of our study [1-4] of arc inception on a triple-junction with a conductor negatively biased with respect to the surrounding plasma. Such a configuration is quite typical for a spacecraft design: interconnect-coverglass junctions on solar array, anodized aluminum layer-bare aluminum, and so on.

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Due to the conventional grounding scheme, the spacecraft body and negative sections of its solar array acquire a negative potential that is close to the array operational voltage under LEO conditions. To decrease ohmic losses in wires and to avoid the necessity of special electronic equipment (converters) for high-voltage devices, a substantial increase in solar array operational voltage appears entirely rational. However, there are a few serious obstacles toward the practical implementation of a high-voltage solar array (over 300 V). One of these obstacles is the thickness of the thermal insulation. It is known that a very thin anodized aluminum layer can provide the required thermal regime. For example, the thickness of thermal insulation for ISS is only 1.27 μm. The electric field strength inside this layer could reach approximately 100 MV/m, which is well above of breakdown limit for anodized aluminum (10 to 20 MV/m). The solution of the problem in the case of ISS is a plasma contactor that keeps a potential difference between the plasma and the spacecraft body in the range below 40 V. Another solution of this particular problem could be to increase the thickness of the insulation. Of course, such a solution has its own drawback: the weight of a 25 μm coating is almost 50 g/m^2. On the other hand, a plasma contactor is also not an ideal solution: it has its own weight, bottles of gas have to be delivered to the spacecraft, the spacecraft potential fluctuates, etc. Further discussion of possible variations in spacecraft insulation design is well beyond the scope of this paper, which is devoted entirely to arcing on triple-junctions. A second serious problem that must be solved prior the employment of a high-voltage solar array is arcing on its surface. These undesirable events have been known for over thirty years, and many research articles and review papers have been published to date [5-9]. The overall result of these comprehensive studies can be formulated as the following: arcing on a negatively biased triple-junction is unavoidable. One radical solution to this problem is using fully encapsulated solar arrays. Another solution (not radical) that seems to be effective is to raise the arc inception voltage by the modification of interconnect-coverglass junctions on conventional solar arrays. To achieve this last goal one must understand the physical mechanisms of arc inception. The current paper is entirely devoted to the study of arcing on solar array samples and a copper-quartz junction immersed in a low-density plasma.

Analysis of arc plasma optical spectra confirms the essential role of adsorbed water molecules for arc development. Estimates of threshold electric field strengths demonstrate clearly that the arc inception voltage can be considerably increased by thoroughly outgassing junctions and smoothing interconnect surfaces. In fact, a sample of a silicon solar array (3 by 3 cell) was kept in a plasma for one hour biased to –500 V with no arcing. Initially, this sample demonstrated arcing on interconnect-coverglass junctions at –120 V. There is reason to believe that changes in arc inception voltages are caused by outgassing of dielectric surfaces—this sample was in vacuum for 176 hours (pressure 2 μTorr). The highest voltage that can be reached by preliminary outgassing is determined by the minimum electric field strength for generation of a vacuum arc. For silver and copper cathodes, this is in the range of E_l=5 to 10 MV/m [10-12]. Thus, a solar array with 200 μm dielectric thickness (coverglass and adhesive) will experience extensive arcing at voltages above 1000 V negative, and achieving operational voltages –300 to 500 V for conventionally designed solar arrays seems possible.

2. ARC PARAMETERS AND SPECTRA

Arc development due to electron impact induced desorption was first considered theoretically over ten years ago [13]. A few years later an arc rate increase with increasing water vapor partial pressure was demonstrated [14]. During the last two years strong evidence has been obtained that preliminary outgassing causes a significant drop in the arc rate [2,3]. Moreover, the experimentally established scaling law (pulse width proportional to the square root of capacitance) was explained within the framework of a simple model of dissociative recombination [4]. All these results incited new experiments to confirm the presence of products of water ion dissociative recombination by straightforward spectroscopic measurements. Arc spectra were obtained for arcs initiated on a solar array sample (Fig. 1) and a quartz-copper junction (Fig. 2). The experimental setup is described in Ref. 15 very completely; thus, the paragraph below is devoted to discussion of the results only. The dependencies of arc rate on bias voltage, gas pressure, and time (conditioning) are shown in Fig. 3. Examples of arc spectra covering the wavelength range 250 to 700 nm are shown in Fig.4. Both a hydrogen line (H_α) and a hydroxyl band were observed in emission for arcs on the solar array sample and the quartz-copper junction. Moreover, their relative intensities are practically equal $\frac{I(H_\alpha)}{I(OH)} \approx 4$ if the most intensive line 306 nm is used as a characteristic of the hydroxyl band intensity. This near equality is a very strong argument in favor of water desorption and an ionization mechanism for electrostatic discharge inception. Atomic metal lines were also observed with high spectral intensity. These lines are easily identified: 324.8 and 327.4 nm copper lines, and 328.1 and 338.3 nm silver lines. According to NIST data [16] the transition probabilities for Ag and Cu are similar and $A \approx 1.4\times10^8 s^{-1}$, while the transition probability for hydrogen is considerably less: $A \approx 0.7\times10^8 s^{-1}$. The ratio of number densities of excited atoms can be estimated as

$$X = \frac{N^*(H)}{N^*(M)} = \frac{I(656)}{I(328)} \times \frac{\alpha(328)\cdot A}{\alpha(656)\cdot A_{32}} \quad (1)$$

where $N^*(M)$ is the number density of excited metal atoms (Cu or Ag), $I(\lambda)$ is the observed line intensity, and $\alpha(\lambda)$ is the photocathode quantum efficiency.

Substituting measured intensities in Eq. (1) results in the following estimate: X = 0.6 to 0.7. One also has to take into account the possibility of electron impact excitation of metal lines (energy level ~3.5 eV) that may greatly increase this estimate (Eq. (1)). It does not seem possible to determine the relative densities of metal and hydrogen ions without a computer simulation of all relative processes in the arc plasma. However, the degree of ionization of water molecules can be estimated by the analysis of two main processes: electron-impact ionization and dissociative recombination. The rate of ionization is given by the following integral:

$$\beta(T_e) = \frac{8\pi}{(2\pi T_e)^{3/2} m_e^{1/2}} \int_{E_{th}}^{\infty} \sigma(E) E \cdot exp\left(-\frac{E}{T_e}\right) dE \text{ cm}^3/\text{s} \quad (2)$$

where E_{th} = 12.61 eV is the ionization threshold, T_e is the electron temperature, and $\sigma(E)$ is the electron-impact ionization cross section (see Fig. 5).

The rate of dissociative recombination can be expressed by a simple formula valid for a low temperature plasma [17]:

$$\gamma(T_e) = 10^{-7} T_e^{-1/2} \text{ cm}^3/\text{s} \quad (3)$$

Then, the ratio of number densities can be calculated as

$$Y = \frac{N(H_2O^+)}{N(H_2O)} = \frac{\beta(T_e)}{\gamma(T_e)} \tag{4}$$

The result of this calculation is shown in Fig. 6. Thus, the degree of ionization of water molecules in an arc plasma with the electron temperature T_e = 4 to 5 eV is Y = 0.01 to 0.04. On the another hand, the degree of ionization of metal atoms can be estimated (though very roughly) as

$$Z = \frac{N(M^+)}{N(M)} \approx \exp\left(-\frac{J}{T_e}\right) \tag{5}$$

where J is the ionization potential (J(Ag) = 7.58 eV, and J(Cu)=7.73 eV).

It follows from the Eq. (5) that metal vapor has a much higher degree of ionization: Z = 0.1 to 0.2.

If one suggests that the main source of electrons is one of the species (H_2O or metal) the amount of material ejected into the plasma due to arcing can be calculated quite simply:

$$m = \frac{C \cdot U}{e \cdot Y} \cdot \mu m_p \text{ g} \tag{6}$$

where U is bias voltage, C is additional capacitance, μ is molecular (atomic) mass, and m_p is proton mass.

For our typical experimental conditions (U = 500 V, and $C = 10^{-6}$ F) the results are shown below:
$m(H_2O) = 4.7$ μg , m(Cu) = 3.3 μg, and m(Ag) = 5.5 μg.

That amount of ejected material would cause remarkable damage to the electrodes in the form of craters with dimensions about 100 μm, which have never been observed. Microscopic analysis of an electrode surface reveals craters of diameter less than 10 μm. There is plainly not enough surface area of a triple-junction to adsorb so much water. One very important conclusion follows from this discussion: an enhanced field emission mechanism plays a decisive role in providing the path for a discharge current. Actually, the electric field strength $E_0 = \frac{U}{d} \approx 1-2$ MV/m is a few times lower than the vacuum arc initiation threshold E_1. It is known that a high electron current density (above $j_{min} = 10^5$ A/m^2) due to field emission is needed to initiate an electron impact induced desorption and electrostatic discharge on a triple-junction [2,6]. Field enhancement factor can be calculated from the Fowler-Nordheim plot (Fig. 7): $\beta = \frac{E(j_{\min})}{E_0} = (1-2)\cdot 10^3$. This rather high enhancement can be achieved by the simultaneous action of at least three known mechanisms (see details in [4,18-19]). Once the ionization avalanche starts, the enhancement factor increases due to the polarization of the dense plasma near the electrode, and the electron current density may reach 10^{12-13} A/m^2 , which is high enough to provide the observed current (20 to 50 A) from a cathode spot of a few microns diameter. The numbers above are in good agreement with experimental data for a copper cathode published in Ref. 20, and the small size of a cathode spot explains failure of earlier attempts to find craters on electrodes with optical microscopy [3,4]. Moreover, previous calculations [21] have shown that the plasma conductivity is high enough to provide a path for electric current with current density above 10^{10} A/m^2.

Thus, straight spectroscopic measurements confirm the idea that electrostatic breakdown on a biased triple-junction immersed in a plasma is caused mainly by gas adsorbed on a dielectric side surface, and geometrical protrusions on an electrode surface. It seems reasonable to show also differences between arc spectra measured on the solar array sample and the quartz-copper junction (Fig. 8). Due to the high volatility of coverglass and adhesives, the arc plasma on the sample contains many molecules and radicals (spectral lines have been identified according to Ref. 22). On the contrary, the arc on the quartz-copper junction reveals only metal atoms and products of water dissociation. This difference in a plasma composition may play some role in the discharge development process, but it does not look important for arc inception-in both cases the critical field is 1 to 1.5 MV/m

3. CONCLUSION

It seems practical to achieve operating voltages of 300 V for conventionally designed solar arrays and to avoid arcing on their surfaces by thoroughly outgassing dielectric surfaces and polishing interconnects. More experiments and tests must be done before a reliable upper limit of operating voltage can be established.

REFERENCES

1. Ferguson, D.C., “Solar Array Arcing in Plasmas,” NASA CP–3059, 1989, p. 509.
2. Vayner, B., Galofaro, J., Ferguson, D., Degroot, W., and Vayner, L., “Arcing Onset on a Solar Array Immersed in a Low-Density Plasma,” 39th Aerospace Sciences Meeting and Exhibit, January 8–11, 2001, Reno, NV (AIAA Paper 2001–0400).

3. Vayner, B., Galofaro, J., and Ferguson, D., “Arc Inception Mechanism on a Solar Array Immersed in a Low-Density Plasma,” 7th Spacecraft Charging Technology Conference, 2001: A Spacecraft Charging Odyssey, April 23–27, Noordwijk, The Netherlands (NASA/TM—2001-211070).
4. Vayner, B., Galofaro, J., Ferguson, D., and Degroot, W., “Arcing Onset on a Metal-Dielectric Junction Immersed in a Low Density Plasma,” Proc. XXV International Conference on Phenomena in Ionized Gases, 2001, July 17–22, Nagoya, Japan, vol. 3, pp. 293–295.
5. Parks, D.E., Jongeward, G.A., Katz, I., and Davis, V.A., “Threshold-Determining Mechanisms for Discharges in High-Voltage Solar Arrays,” Journal of Spacecraft and Rockets, 1987, vol. 24, no. 4, pp. 367–371.
6. Hastings, D.E., Weyl, G., and Kaufman, D., “Threshold Voltage for Arcing on Negatively Biased Solar Arrays,” Journal of Spacecraft and Rockets, 1990, vol. 27, no. 5, pp. 539–544.
7. Mong, R., and Hastings, D.E., “Arc Mitigation on High Voltage Solar Arrays,” Journal of Spacecraft and Rockets, 1994, vol. 31, no. 4, pp. 684–690.
8. Cho, M., Miyata, N., and Hikita, M., “Effects of Arcing on Insulator Surface Charging Condition in Plasma Environment,” 38th Aerospace Sciences Meeting and Exhibit, January 10–13, 2000, Reno, NV (AIAA Paper 2000–0872).
9. Hastings, D.E., “A Review of Plasma Interactions with Spacecraft in Low Earth Orbit,” Journal of Geophys. Res., 1995, vol. 100, no. A8, pp. 14457–14483.
10. Handbook of Vacuum Arc Science and Technology, eds. R.L. Boxman, D.M. Sanders, and P.J. Martin. NP, New Jersey, USA, 1990.
11. Anderson, R.A., and Brainard, J.P., “Mechanism of Pulsed Surface Flashover Involving Electron-Stimulated Desorption,” Jour. Appl. Phys., 1980, vol. 51, no. 3, pp. 1414–1421.
12. Mesyats, G.A., “Ectons and Their Role in Electrical Discharges in Vacuum and Gases,” Journal De Physique IV, 1997, vol. 7, no. 10, pp. 93–112.
13. Hastings, D.E., Weyl, G., and Kaufman, D., “Threshold Voltage for Arcing on Negatively Biased Solar Arrays,” Journal of Spacecraft and Rockets, 1990, vol. 27, no. 5, pp. 539–544.
14. Upschulte, B.L., Marinelli, W.J., Carleton, K.L., Weyl, G., Aifer, E., and Hastings, D.E., “Arcing on Negatively Biased Solar Cells in a Plasma Environment,” Journal of Spacecraft and Rockets, 1994, vol. 31, no. 3, pp. 493–501.
15. Galofaro, J., Vayner, B., Degroot, W., and Ferguson, D., “The Role of Water Vapor and Dissociative Recombination Processes in Solar Array Arc Initiation,” 40th Aerospace Sciences Meeting and Exhibit, January 14–17, 2002, Reno, NV (AIAA Paper 2002–0938).
16. NIST Atomic Spectra Database Lines Data, http://physics.nist.gov
17. Kaplan, S.A., and Pikel’ner, S.B., “Physics of Interstellar Medium,” 1979, Nauka, Moscow, p. 376.
18. Jimenez, M., Noer, R.J., Jouve, G., and Bonin, B., “Electron Field Emission From Large-Area Cathodes: Evidence for Projection Model,” Journal Phys. D.: Appl. Phys., 1994, vol. 27, pp. 1038–1045.
19. Jǔttner, B., “Cathode Spots of Electric Arcs,” Journal Phys. D.: Appl. Phys., 2001, vol. 34, pp. 103–123.
20. Mesyats, G.A., “Cathode Phenomena in a Vacuum Discharge,” 2000, Nauka, Moscow.
21. Snyder, D.B., Ferguson, D.C., Vayner, B.V., and Galofaro, J.T., “New Spacecraft-Charging Solar Array Failure Mechanism,” 6th Spacecraft Charging Technology Conference, 1998, October 26–29, Hanscom AFB, MA, USA (Publ. AFRL–VS–TR–20001578).
22. Pearse, R.W.B., and Gaydon, A.G., “The Identification of Molecular Spectra,” Chapman & Hall Ltd., London, UK, 1963, p. 345.

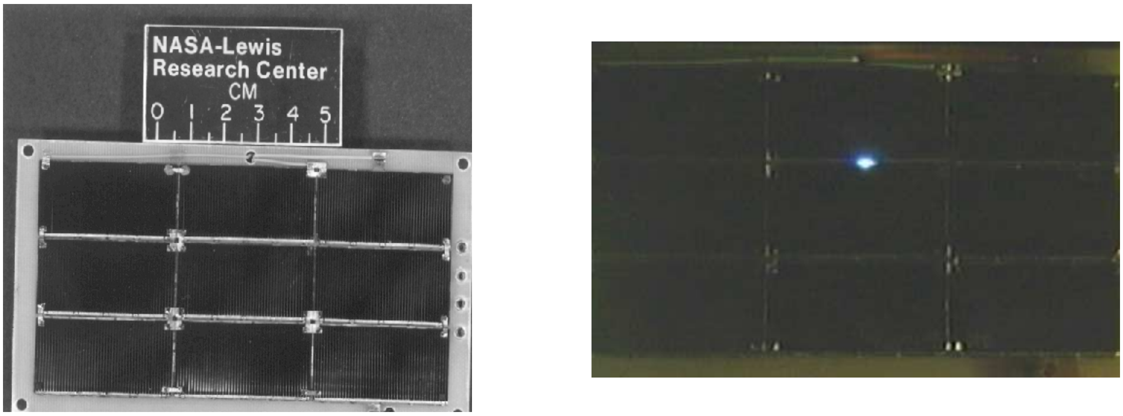


Figure 1. The solar array sample is shown arcing in the plasma chamber (right). The size of the sample is shown on the left.

Figure 2. The quartz-copper junction is shown before insulating its backside with RTV (left panel), and arcing in the plasma (right panel).

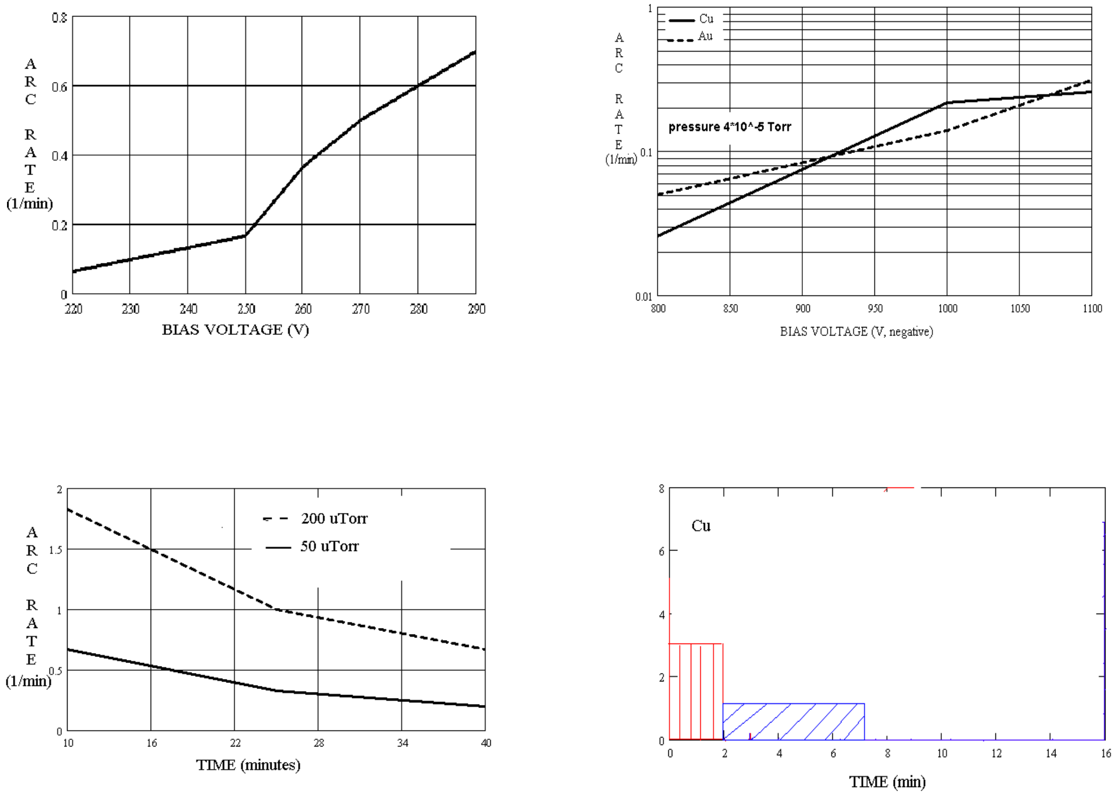


Figure 3. Arc rate vs. bias voltage and time (conditioning) is shown the for solar array sample (left panel) and the quartz-copper junction (right panel).

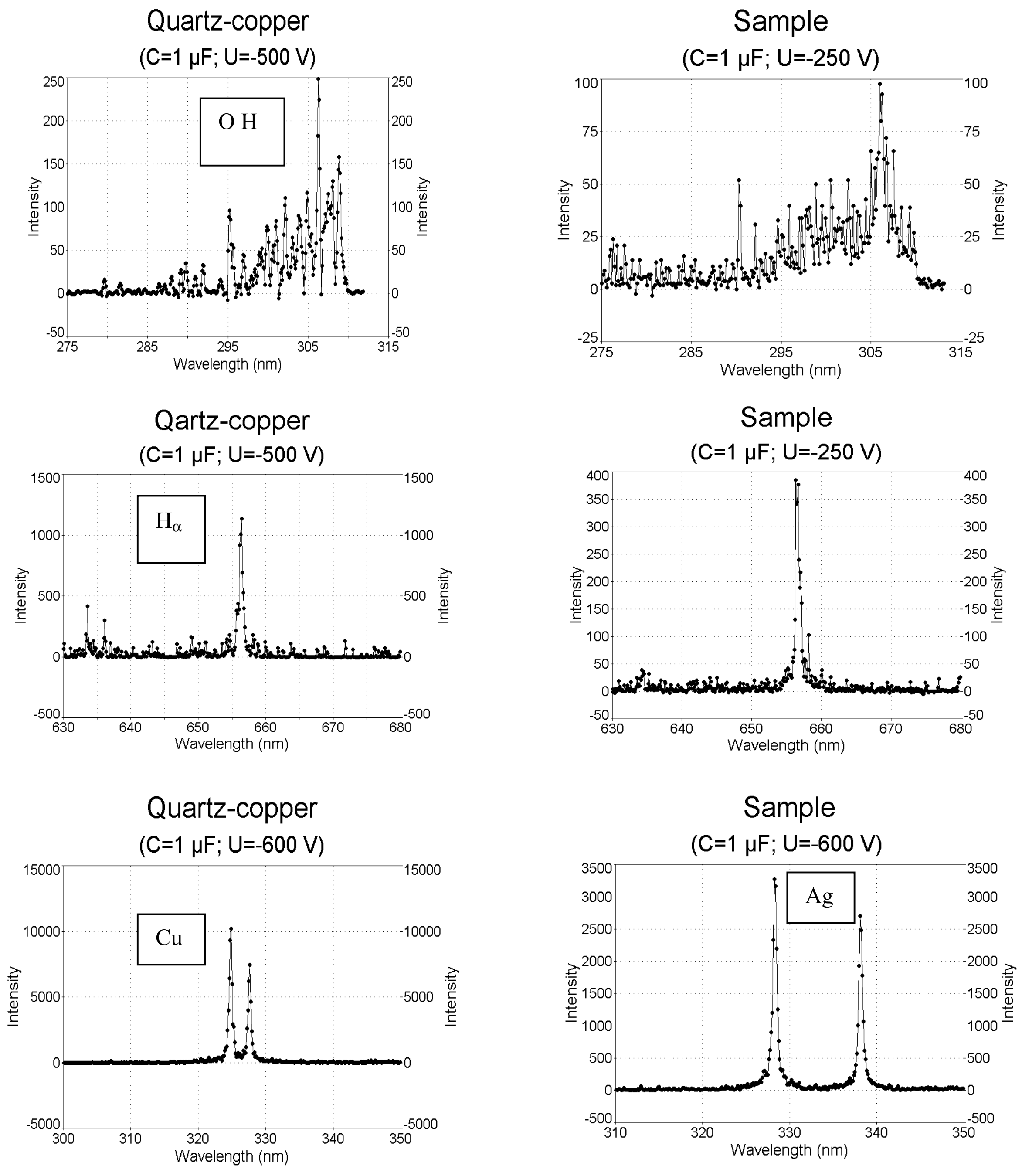
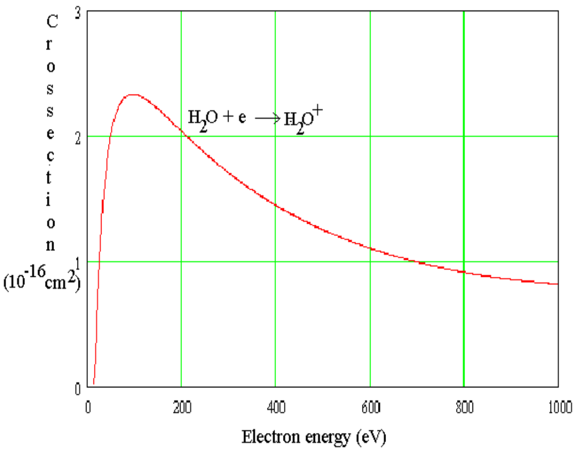


Figure 4. Arc spectra demonstrate the presence of hydroxyl and hydrogen in the arc plasma. Metal atoms play an important role in arc development.



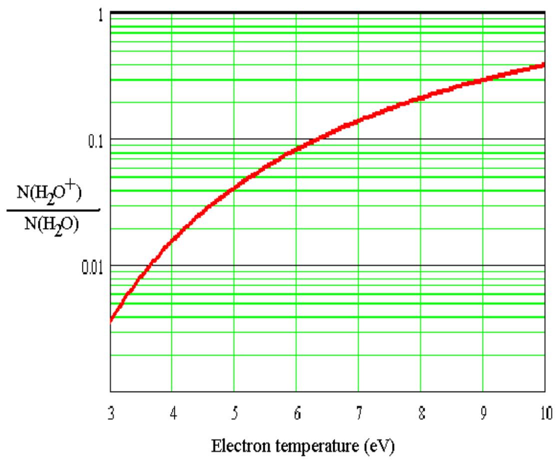


Figure 5. Electron impact ionization cross section is shown for water molecules in the ground state.

Figure 6. The degree of ionization vs. electron temperature.

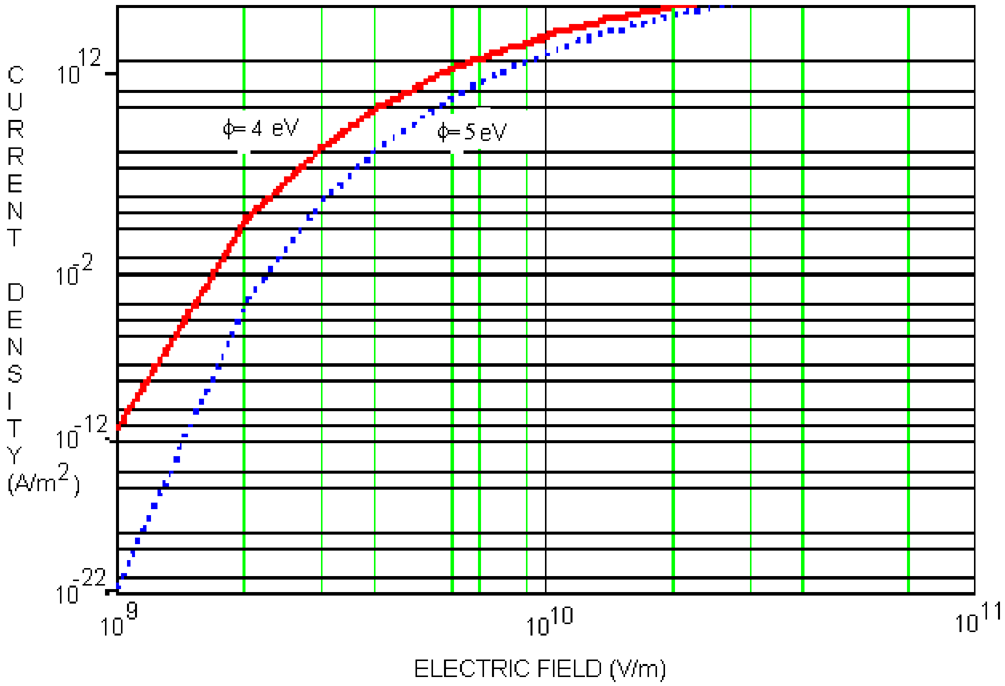


Figure 7. Fowler-Nordheim current density is shown for two metals with work functions of 4 and 5 eV respectively.

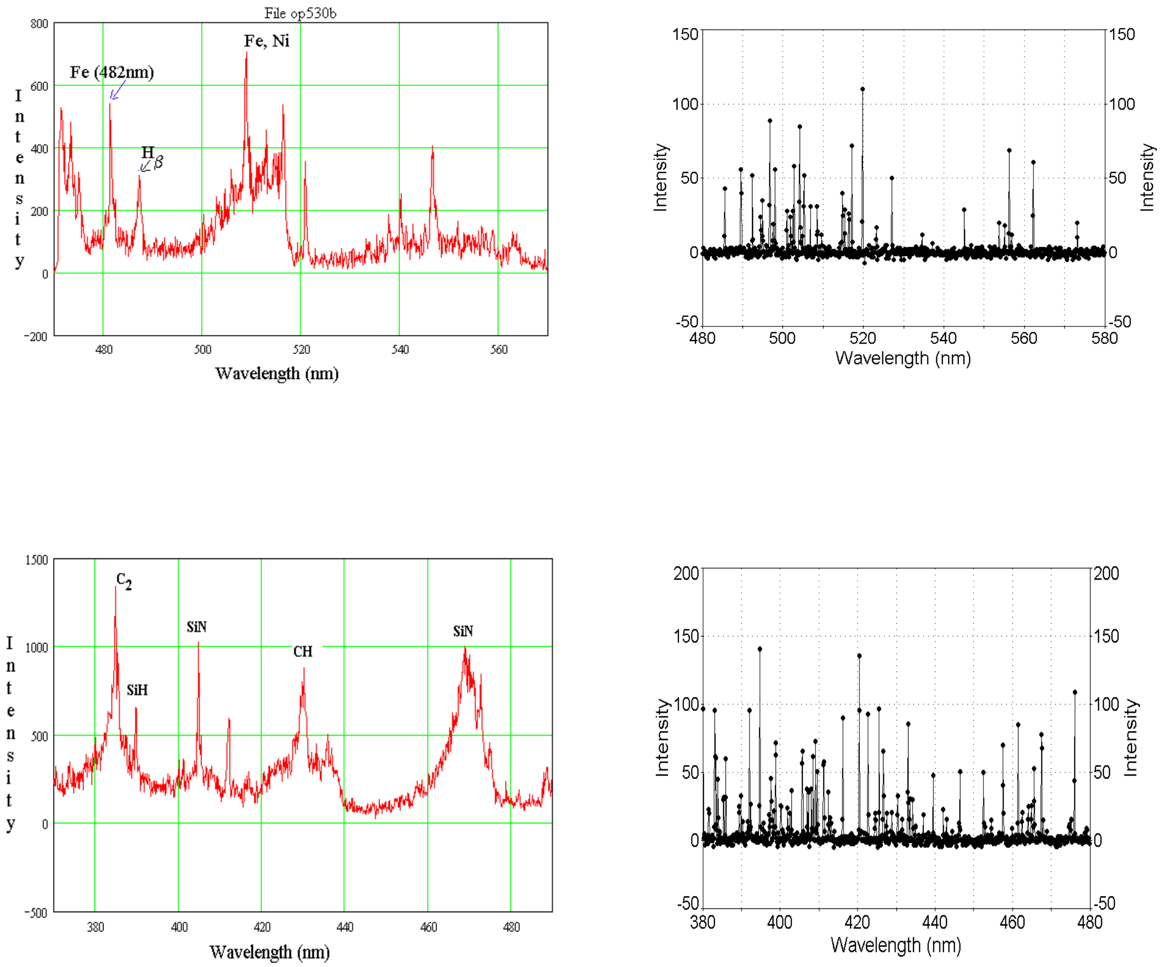


Figure 8. Spectra of arcs on the solar array sample reveal many lines of molecules and radicals (left panel). On the contrary, no line has been identified for spectra of arcs on the quartz-copper junction (right panel).

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